ceding twenty-three years. The year 1886 has been included with those following because it was a decline in the precipitation that year which caused the lake to fall the following year. Of course the average for the entire period gives the best normal, and, as the comparison of the average for the last fifteen years with this normal, shows an average shortage of 0.98 inch for each year, the total shortage for the fifteen years ending 1900 is 14.70 inches. With a shortage of 14.70 inches in rainfall a decided fall in the lake level would naturally be expected, and a fall of about 9 feet and 11 inches occurred. The fall was from a maximum of about 9 feet 2 inches in 1886 to a minimum of minus 9 inches at the close of 1900.

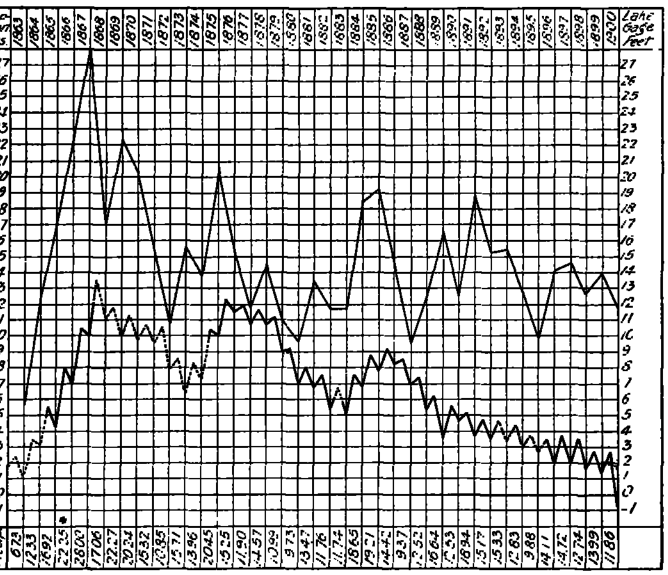

FIG. 2.—Chart showing average annual precipitation of Great Salt Lake basin as obtained from the records of three stations, Salt Lake City, Ogden, and Corinne, and fluctuations of water level of Great Salt Lake from 1863 to 1900.

The upper line indicates the precipitation and the lower one the lake level.

Dotted line indicates periods of no authentic observations or that the data have been approximated.

The lake level from 1863 to 1890 is from a diagram published by the Oregon Short Line Railroad Company, and based upon data furnished by Prof. Marcus E. Jones.

The average precipitation for the fifteen years preceding 1886, or from 1871 to 1885, inclusive, was 14.24 inches, which is 0.57 inch greater than the average for the fifteen years ending 1900, but 0.41 inch below the normal. The average for the eight years from 1863 to 1870, inclusive, approximating the precipitation of 1866 at 22.25 inches, is 18.22 inches, or 3.57 inches above the normal. The wettest fifteen consecutive years were those from 1864 to 1878, inclusive, with an average of 17.14 inches, and during this period the lake rose to a maximum height of about 13 feet 5 inches in 1868, fell to a minimum of about 6 feet in 1874, and reached a maximum height of about 12 feet 5 inches in 1876. The rise of 1868 was preceded by 28 inches of rainfall in 1867, and the rise of 1876 by 20.45 inches in 1875.

The question now arises, is the climate of the Great Salt Lake basin becoming drier?

The climate of the Great Salt Lake basin is not changing. The average precipitation for the next fifty years will agree very closely with the average for the past fifty years. Periods of heavy precipitation will occur again, and following them the lake will rise to about the same levels reached by it in the past.

* Approximated.

THE WATER LEVEL OF GREAT SALT LAKE.

By Mr. G. K. GILBERT, U. S Geological Survey, dated February 8, 1901.

The data Mr. Murdoch has brought together I find interesting, not only because they relate to a subject which occupied my attention some years ago, but because they give an unexpected attestation to the value of the ordinary record of precipitation. For various reasons it has been thought that the rain gage records but imperfectly the actual precipitation of the locality where it is placed, and also that the precipitation record at a single locality in an arid district represents very imperfectly the march, from year to year, of the average precipitation of the surrounding region. Mr. Murdoch's table compares a local precipitation record with the variations of a water surface so situated as to be greatly influenced by variations of the precipitation on a neighboring mountain range, and the accordance of the two records seems to me remarkably good.

Omitting the years for which the lake water record is interpolated, I find from the graphic table that there are twenty-three annual records susceptible of direct comparison with the rain-gage record. For each of these twenty-three years, I have compared the rain-gage record with the normal, noting the excess or defect of precipitation, and I have also compared the records of lake level for the beginning and end of the year, noting whether, and how much, the level has risen or fallen. The correspondence of excess of precipitation with the rise of the lake, and of defect of precipitation with the fall of the lake, is almost complete, there being but three years of the twenty-three in which a deviation of precipitation from the normal to the extent of one inch, is not accompanied by a change of lake level having the proper sign.

Finding the data thus accordant, I have thought it legitimate to carry the discussion a little further than Mr. Murdoch has done. He has shown that the recent great fall of the lake surface corresponds to a period of defective precipitation, but he has not attempted to show whether the change in precipitation is fully adequate to account for the lowering of the lake. Making use of his tables, and neglecting as before, the years for which the lake record is interpolated, I find that there were eight years in which the recorded precipitation exceeded the normal, the total excess amounting to 36.46 inches. In six of those eight years the lake rose 9.9 feet, and in other two it fell 2.8 feet, leaving a net rise of 7.1 feet. In fifteen years the rainfall was less than the normal, giving a total defect of 32.99 inches. In thirteen of those years the lake fell 12.4 feet, and in the other two rose 1.5 feet, leaving a net fall for the period of 10.9 feet. Summing these data, without regard to signs, we have a total of deviations of precipitation from the normal amounting to 69.45 inches, corresponding to a total of accordant changes in the level of the lake amounting to 18.0 feet. This gives 0.26 foot as the amount of lake change corresponding to one inch excess or defect of precipitation, and we may apply this factor to the period of defective rainfall mentioned by Mr. Murdoch. In the fifteen years, from 1886 to 1900, inclusive, the total shortage of rainfall is 14.70 inches, and this, according to the scale just determined, will account for 3.82 feet of fall in the lake. The actual fall was considerably greater, being 9.9 feet.

While this discussion is not fully satisfactory, and is open to the objection that the lake change per unit of precipitation is derived in part from some of the same observations to which it is afterwards applied, it may yet be accepted as indicating that shortage of rainfall does not suffice to account for the whole of the fall of the lake surface.

The problem is complex, and if a complete analysis were possible, it would probably serve to show that a number of factors have conspired to produce the observed shrinkage of the lake. I apprehend that a prominent place among these factors would be accorded to irrigation, or the diversion to cultivated fields of waters which would otherwise flow unimpeded to the lake. I understand that the area of irrigated land within the drainage district of the lake has been greatly enlarged during the last decade, and I do not see how this could fail to influence that balance between inflow and evaporation which determines the height of the lake. The water spread upon the farm lands is in part evaporated directly, and in part transpired by plants, and both these parts are carried away by the air. A portion also finds its way into the ground, and eventually reaches the lake through springs. That which enters the air increases the local relative humidity, and doubtless increases precipitation on the great mountain range to the eastward, so that a portion of it is returned to the rivers, but as the period of principal evaporation and transpiration from the land does not correspond with the period of principal precipitation on the mountains, it is probable that the share of irrigation water thus prevented from escaping the drainage basin is not great. It certainly is not sufficient to prevent the work of irrigation from greatly diminishing the amount of water which the rivers discharge to the lake.

In the natural condition of the country, before the advent of the white man, the rise and fall of the lake was a climatic index responding to the conjoined influences of variations in temperature, precipitation, and wind. Had the gage record been then kept it would have constituted a valuable contribution to the history of climate. But the same immigration, which instituted observations of lake changes, also established various industries tending to modify the condition of the land and interfere with the reaction of natural agencies, and now that agriculture is striving to divert to its own purposes as much as possible of the normal tribute of the lake, the gage has practically lost its value as a register of climate. Much interest, both economic and scientific, still attaches to its readings, and part of that interest is meteorologic, but it has become practically impossible to discriminate between the consequences of natural and human influences.

FOG STUDIES ON MOUNT TAMALPAIS: NUMBER 3—PHOTOGRAPHS OF FOG BILLOWS.

By ALEXANDER G. MCADIE, Forecast Official.

In several papers presented to the Royal Academy of Sciences of Prussia Prof. H. von Helmholtz has discussed the conditions which must occur in the atmosphere where strata of different densities lie close together, with particular reference to the billow and wave effects near the limiting surfaces of the strata.

> It appears to me not doubtful,[1] says Helmholtz, that such systems of waves occur with remarkable frequency at the bounding surfaces of strata of air of different densities, even although in most cases they remain invisible to us. Evidently we see them only when the lowest stratum is so nearly saturated with aqueous vapor that the summit of the wave, within which the pressure is less, begins to form a haze.

It is probable, as Helmholtz states, that conditions favorable for the origin and propagation of air waves often exist, but with the exception of certain cloud forms it is seldom that the meteorologist has an opportunity to see this wave action clearly defined. It therefore seems of importance to present a few photographs showing the actual wave effects produced probably by the sharp contrasts of air currents of different densities in the vicinity of Mount Tamalpais. In the preceding papers[2] the contour of the land and the character of the strong indraft of water vapor having a mean temperature of about 12° C., and which is suddenly injected into a mass of air having a mean temperature of about 24° C., have been described in detail.

It is thought that in the photographs of fog billows (Plates I and II) there is evidence of the movement of rectilinear waves propagated with little change of form and velocity along the bounding surfaces of the different air strata.

With a wind velocity of 10 meters per second, which nearly corresponds with the mean velocity of the inflowing colder current (the average summer afternoon velocity of the wind through the Golden Gate is about 22 miles per hour), the wave length, λ, is determined by von Helmholtz to be about 900 meters (2,950 feet). The wave lengths shown in the various fog photographs herewith are of corresponding magnitude and vary, it is estimated, from 100 to 2,000 meters. Helmholtz states further:[3]

> Since the moderate winds that occur on the surface of the earth often cause water waves of a meter in length, therefore the same winds acting upon strata of air of 10 degrees difference in temperature maintain waves of from 2 to 5 kilometers in length.

Equations for the velocity of propagation and the diminution of the speed with a change of the depth of the lower stratum and a discussion of the energy of the waves are given for special cases. It is also pointed out that the elevations of the air waves can amount to many hundred meters, and that precipitation could thus be mechanically brought about. The same wind can excite waves of different lengths and velocities, and the interference and reinforcement may perceptibly modify the wave form. One of the processes by which waves of great height can be formed is thus pointed out by Helmholtz, namely, where two wave summits of different groups of waves reinforce each other. The wave height may be so great that foaming is produced. Such long and deep waves may have a bearing on the explanation of certain local and nonperiodic disturbances.

The demonstrated existence of these air billows and waves is important also in connection with the transmission of other air waves. It is well known that sound waves are reflected and refracted in a marked degree in the vicinity of fog banks, fog walls, and fog billows. The inaudibility of fog signals from sirens is one of the greatest sources of danger and anxiety in navigation. Any increase in our knowledge of the dispersion and aberration of these fog signals will be hailed with joy by many thousand travelers. In the vicinity of San Francisco, as evidenced by the series of photographs accompanying these papers, the opportunities for studying the general aberration of sound waves in fog are excellent. It is our earnest hope that in due time some experimental work in this direction may be undertaken at the observatory on Mt. Tamalpais. Some very strange effects have already been noticed with regard to the noise of a train when traversing different air strata.

Zones of audibility appear to be quite sharply marked, even after making allowance for the many canyons and "mesas" (tablelands). On foggy days these zones are greatly modified. In addition to changes in density and temperature which sound waves would experience, there are changes due to the movement of the sound conveying medium. The strong air currents moving toward the listener increase the frequency of vibration, and raise the pitch; conversely the air currents moving away from the listener flatten the note.

There have been several instances on nights without fog where ordinary sounds have been heard distinctly a distance of nearly two miles. On other occasions it has been possible to obtain echoes from hills distant one-half mile or more when the intervening valley was covered with fog. The echoes could not be heard when the fog was absent.

The accompanying photographs may throw light upon the

[1] See Abbe's Mechanics of the Earth's Atmosphere, p. 94.

[2] See MONTHLY WEATHER REVIEW, August, 1900, p. 283, and November, 1900, p. 492.

[3] See Mechanics of the Earth's Atmosphere, p. 103.